Can space geodetic data be used as a complement to satellite gravity data in the future?

i.e. non-satellite gravimetry?

Tonie van Dam

thanks to Xiaoping Wu and John Ries for their useful comments on this presentation

GRACE has been providing global gravity fields since 2002

The data have contributed immensely to our understanding of the ma
transport of the planet

Problems still remain in the GRACE data where we must rely on inpu
from other techniques

- at low degrees...C20 not reliable; C21/S21 trends differ from SLR polar motion estimates; GRACE does not give us geocenter but degree-1 harmonics are needed to resolve complete field

- at high degrees...GRACE is used as truth to verify other technique (usually models or inversions of global GPS data sets)

oose roadmap for the presentation

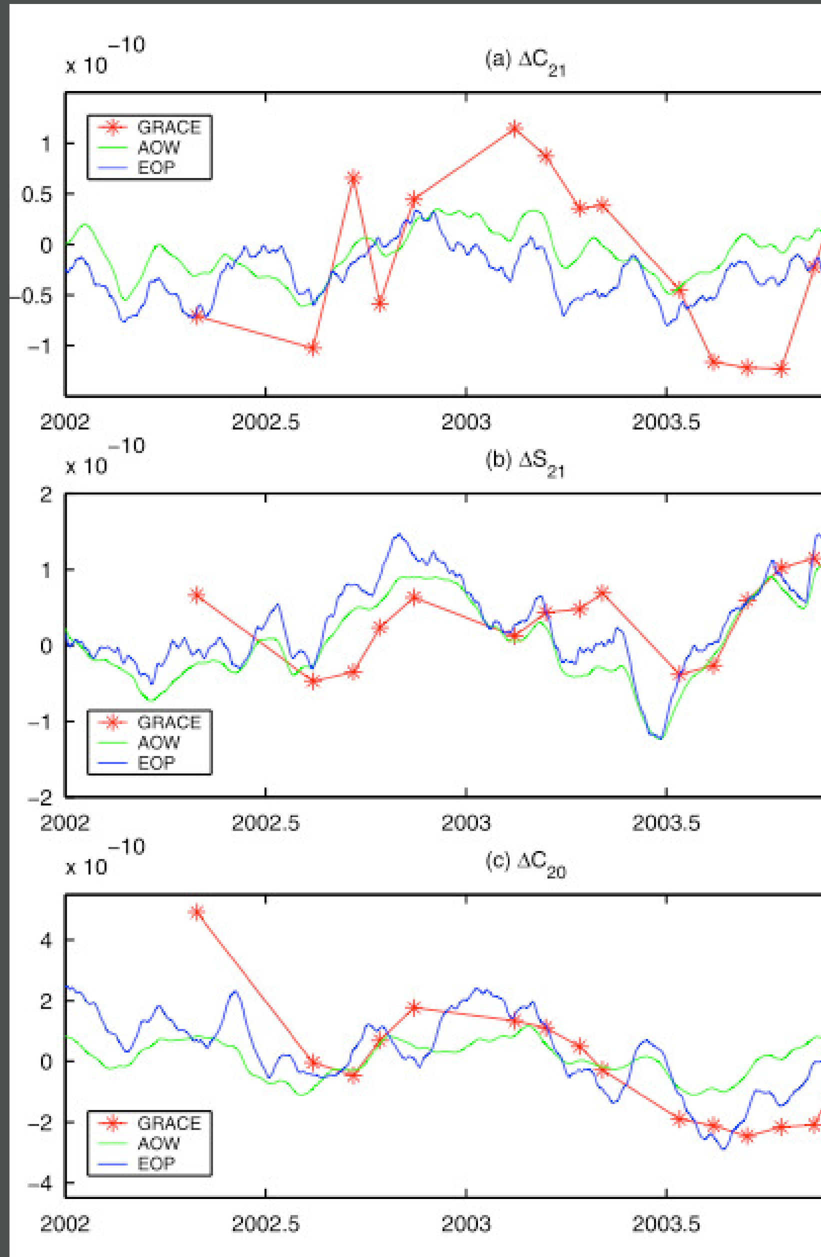
- comparison at low degrees

- comparison at high degrees

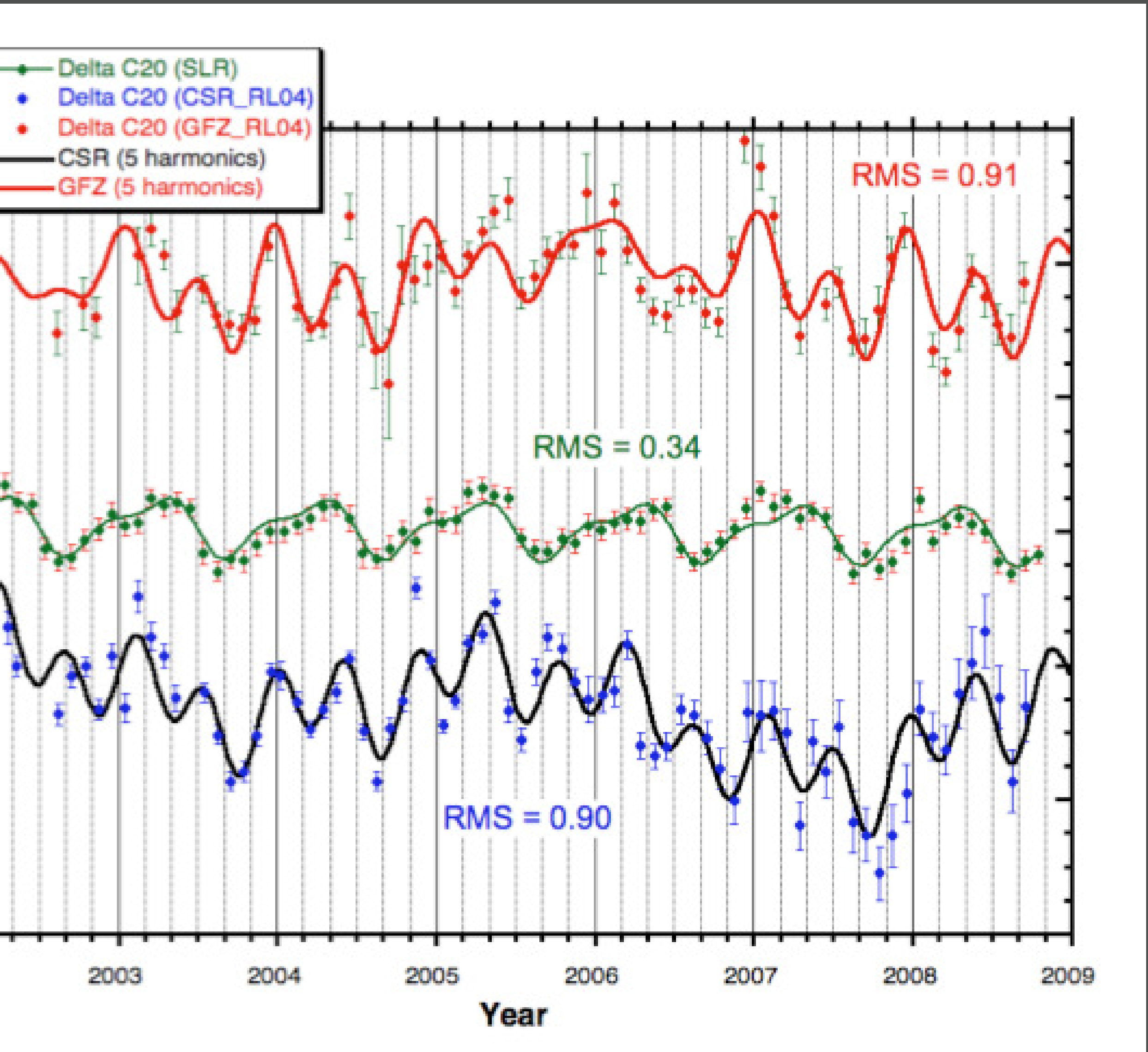
- finish with some general conclusions

Chen et al., GRL (2004)

- ΔC_{21}, ΔS_{21}, and ΔC_{20} (in blue) estimated from Earth rotational data and by a model of atmosphere, ocean and winds (in red)
- The degree 2 variations ΔC_{21}, ΔS_{21}, and ΔC_{20} estimated from (EOP) data appear to have better accuracy than those derived from GRACE (at least compared to the model)
- Satellite laser ranging (SLR) can accurately measure the degree-2 zonal gravitational change, ΔC_{20}, and provides an independent constraint on GRACE ΔC_{20}; a published SLR series was not available at the time this paper was published



lette, Stella, Ajisai



Ries et al., G13A-0632 Fall AGU

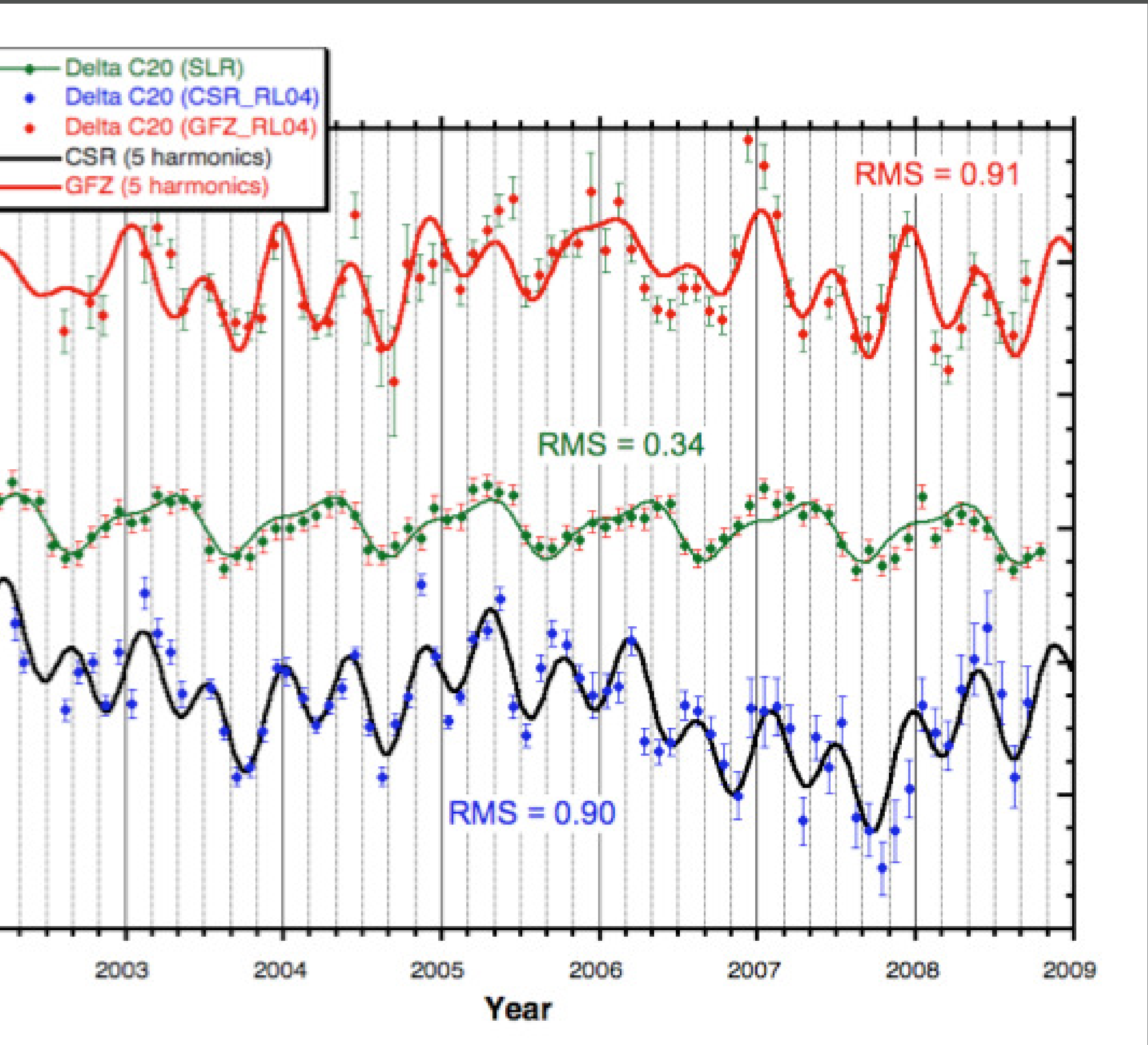
estimate from GRACE da
particularly due to the presence of several long period tidal aliases

- S2 (alias period ~ 161
- K2 (alias period ~ 3.8
- K1 (alias period ~ 7.6

- the signature of the long-period aliasing is visible the CSR and GFZ RL04 series
  - source of the error is unclear; but the ampli appears to be too larg be due to ocean tide

Ajisai

- fit with annual and semiannual accounts 77% of the variance



- CSR and GFZ RL04 seri with annual, semiannual, tidal alias periods
  - explains large non-se variations in C20
  - accounts for 60% and of the variance in GFZ CSR estimates respe
- RMS for GRACE is ~ 3 ti higher than for SLR
- time series is still too sho

s et al., G13A-0632 Fall AGU

es et al., G13A-0632 Fall AGU

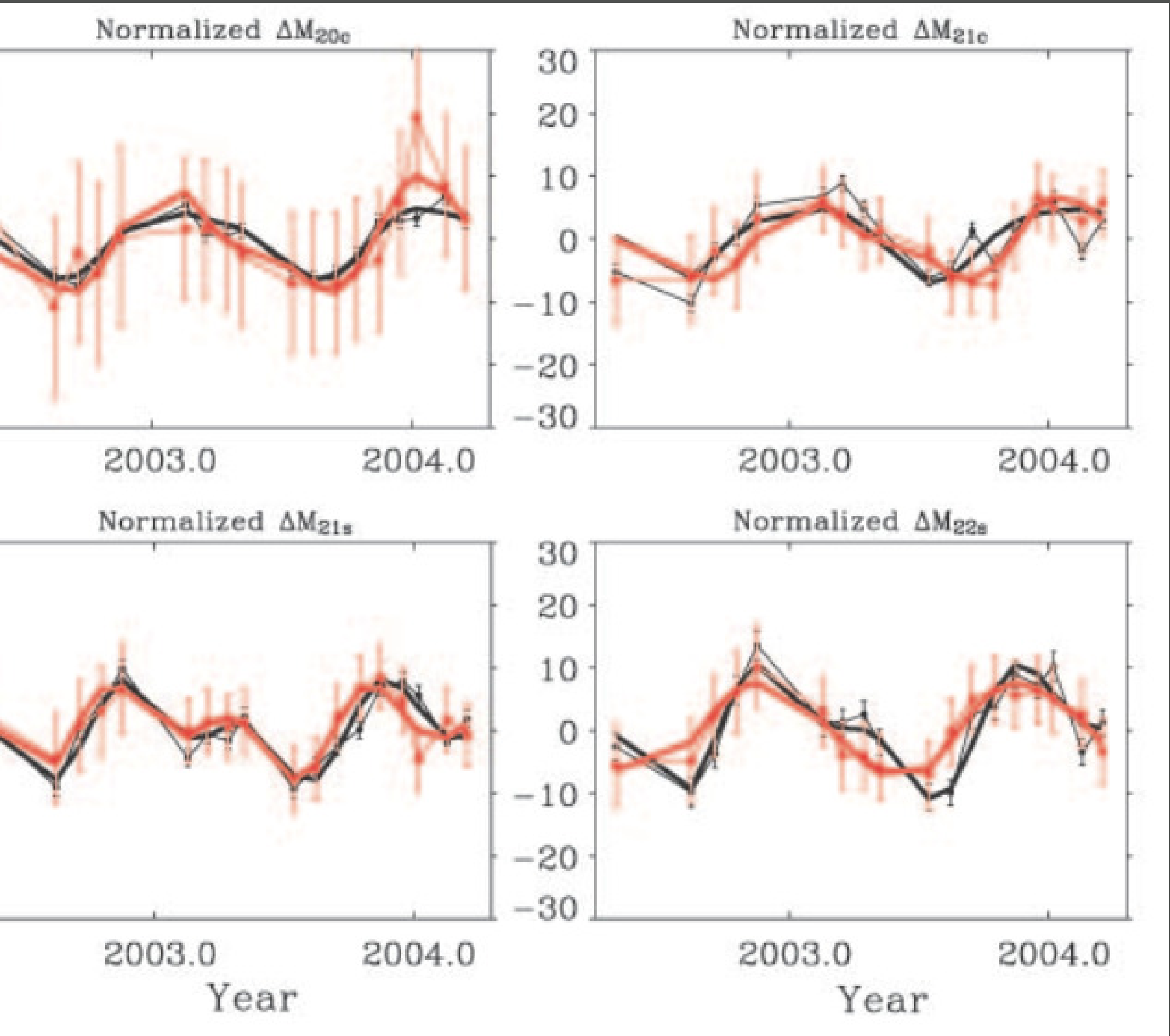
	annual		semiannual		S2		K2		K1	
	amp	phase	amp	phase	amp	phase	amp	phase	amp	pha
SLR	0.76	78	0.32	280	-	-	-	-	-	-
CSR RL04	0.73	71	0.15	293	1.1	74	1.3	290	1.0	20
GFZ RL04	0.85	18	0.68	327	0.7	64	0.6	326	0.3	33

Units: amplitude (1×10^{-10}) phase (degree)

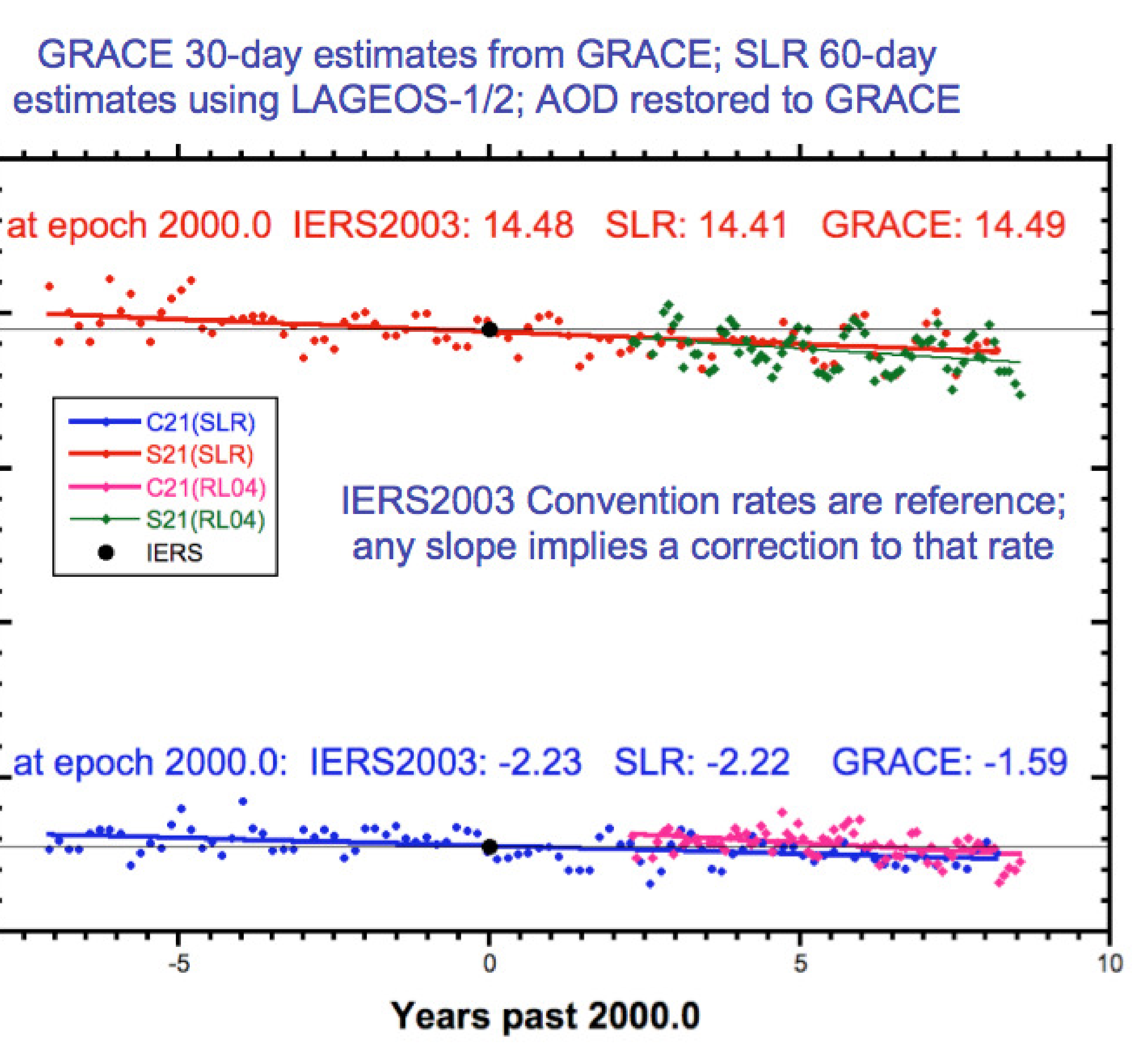
for the annual frequency, CSR series is close to SLR

for the semiannual, agreement with SLR is poor for both

amplitudes of aliases in GFZ versus CSR are systematically smaller



- Wu et al., JGR (2006)
- Joint inversion of GPS
data for annual variati
degree 1 to 50
- Figure 3 from that pap
comparison of the deg
surface mass density
coefficients estimated
a combined GPS/OBP
inversion (black) and
GRACE (red)
- the comparison looks
good; even for the 2,0
component
- only 21 months versus



al., G13A-0632 Fall AGU

- SLR (LAGEOS-1/2) estimates agree with conentions at epoch 2
but a significant slope difference is observed
the next slide)
- extrpolating GRACE to 2000.0 is speculative b
results are not bad
- Seasonal signal is sma
C21 so agreement is n
apparent as for S21
- Both series indicate a correction to the IERS

trends

- JPL and CSR C21 trends have a different sign
- replacing C21 and S21 with polar motion data is not an optimal sc as there are signals in the polar wander data, Markowitz decadal fluctuations, that are still not well understood (X. Wu Personal Communication)

CSR and JPL level-2 data do not agree in the low degrees

- SLR alone has trouble separating coefficients as low as 4x4

potential solution to resolve low degree harmonics might be to proce GRACE and SLR jointly (e.g. Moore et al., JGR (2005))

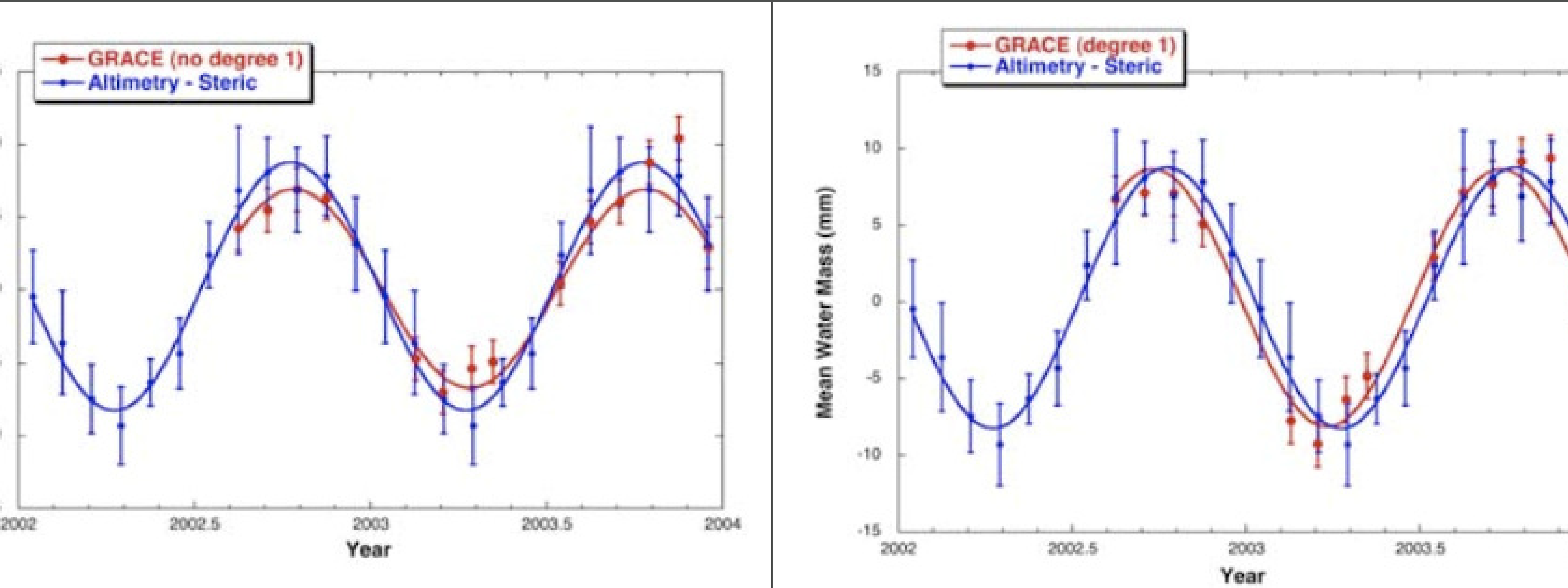
GRACE does not give us degree 1

BUT...

- the complete recovery of a surface mass variation requires knowle
of all its spherical harmonic coefficients

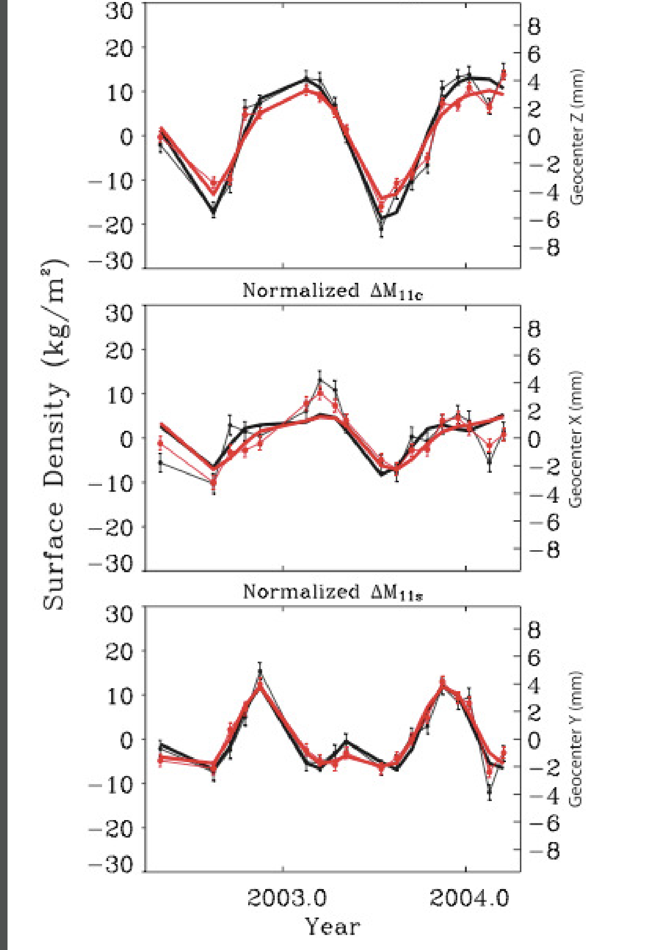
- including degree 1 terms is important if one is looking at just one component of mass variability, since the geocenter variations aris
from transporting mass among and within all components of the m
field

Chambers et al. GRL (2004) compared seasonal mean sea level variations from GRACE and steric-corrected Jason-1 altimeter data



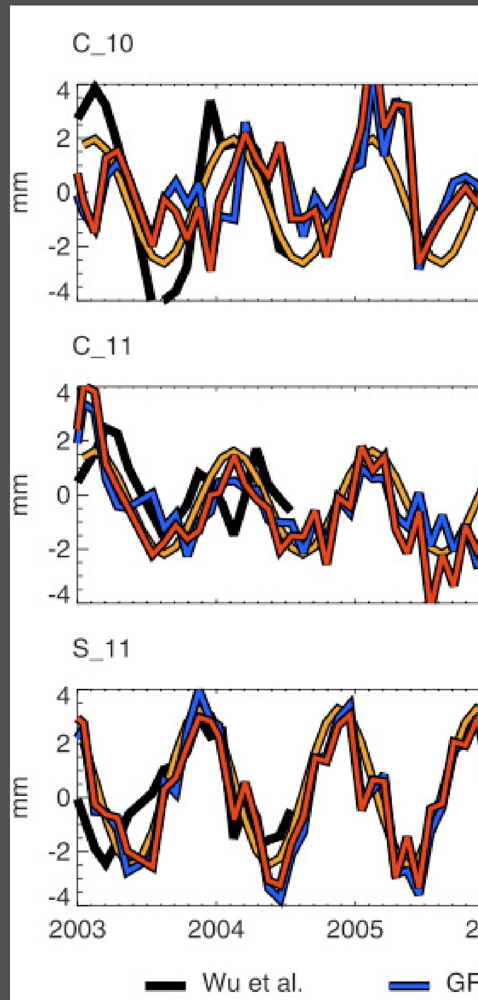
- converted annual estimates of geocenter motion from Chen et al., JG (1999) and to degree-1 gravity coefficients
- found differences in annual amplitudes on the order of 15% that were reduced to 1% by the addition of a seasonal degree one estimate

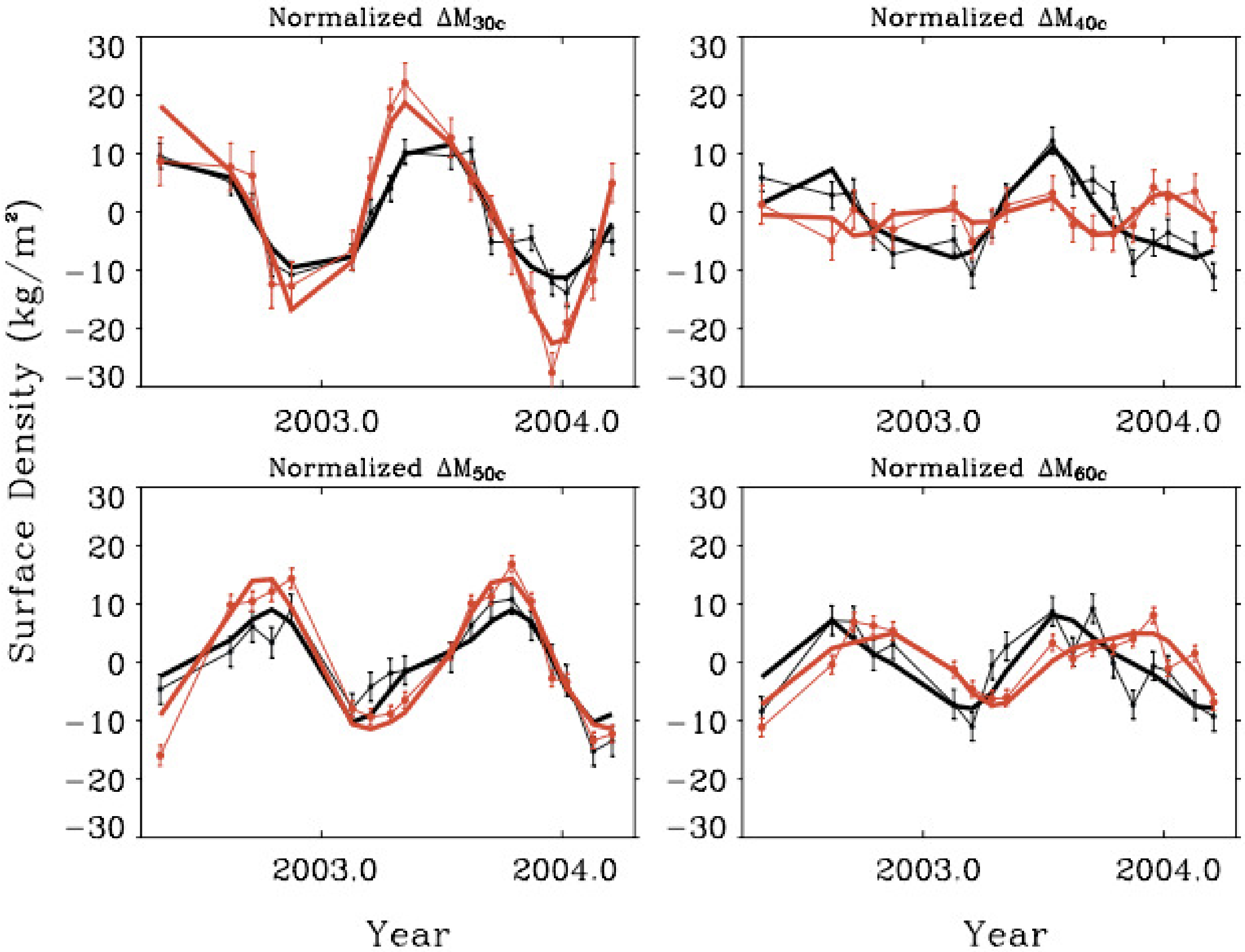
- degree-1 is a global signal
- currently derived from SLR geocenter, which is derived from a sparse global network => reliability (?)
- might be better to consider the approach of Wu et al., JGR (2006)
    - inversion of global GPS data combined with OBP over the oceans and GRACE
- Swenson et al., JGR (2007) geocenter from GRACE plus ocean mass model



GPS/OBP black

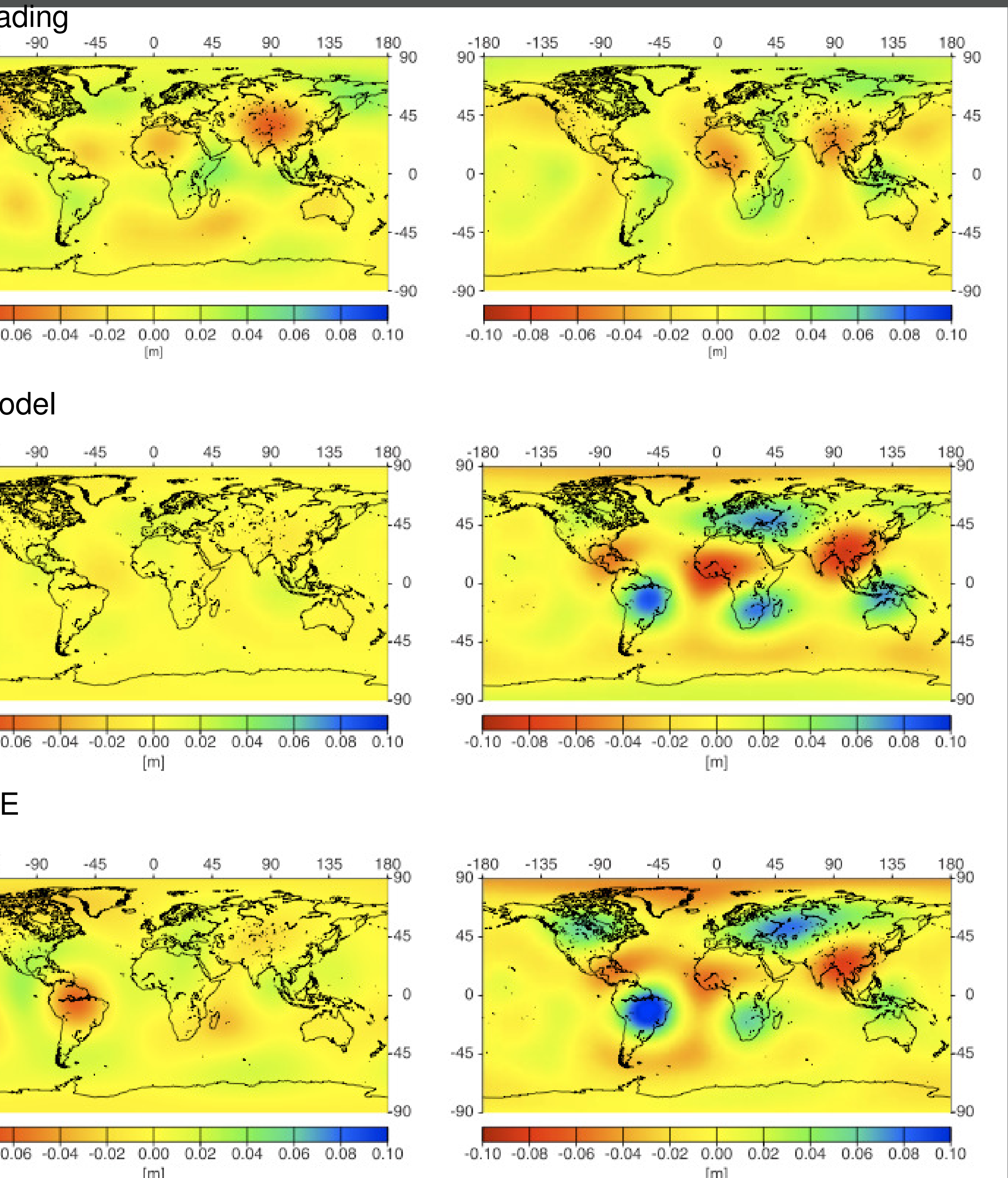
GPS/OBP/GRAC





Normalized ΔM_{30c}
Normalized ΔM_{40c}
Normalized ΔM_{50c}
Normalized ΔM_{60c}
Surface Density (kg/m²)
30
20
10
0
−10
−20
−30
2003.0
2004.0
Year

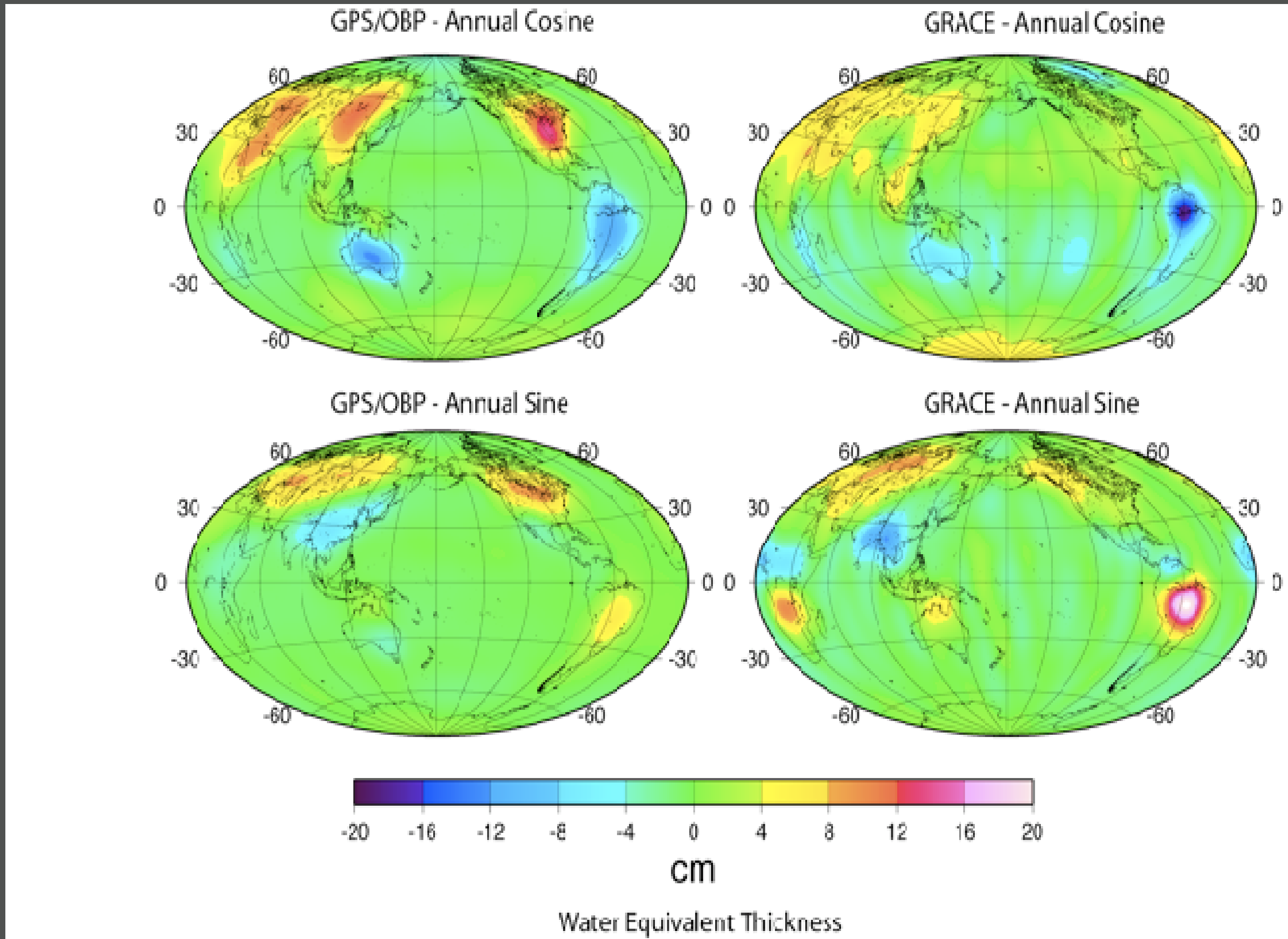
cosine sine



- GPS, CPC, GRACE
  - annual surface density in t
    equivalent water height (m
  - inversion compared to GR
    and CPC hydrology model
  - expansion l=3 to 6
  - results: good correlations f
    certain spherical harmonic
    coefficients or for some lar
    basin averages
- there is a mismatch relative to
  GRACE in spatial patterns an
  particularly with the amplitude

Figure 4, Kusche and Schrama, JG

Figure 5 Wu et al. JGR (2006): joint inversion of GPS/OBP data for annual variations (complete spectrum up to degree 50)

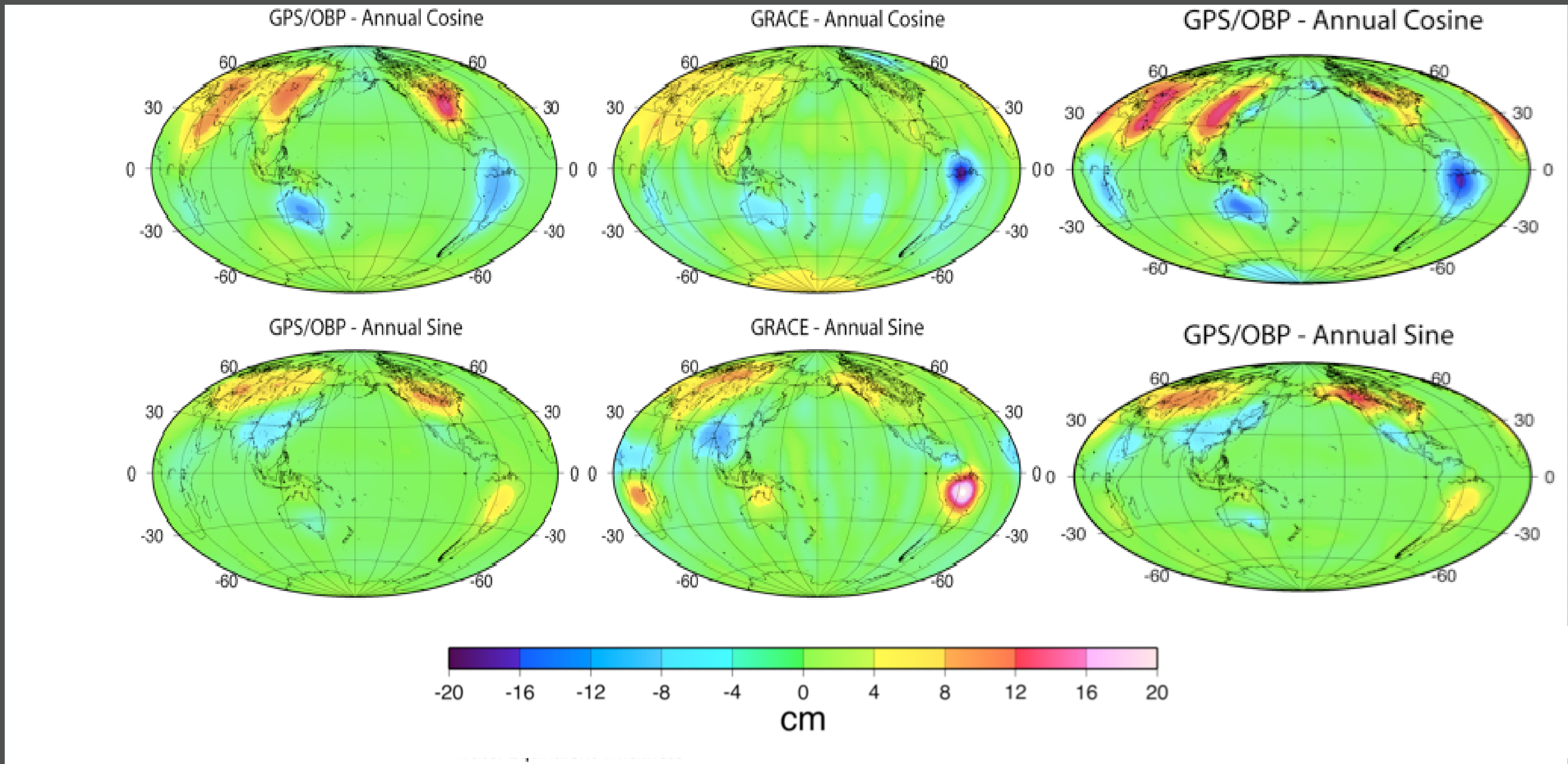


geographical patterns of mass distribution similar (but not perfect); la
disagreement in amplitudes

s the lack of better agreement due to GPS technique-specific issues

Rapid improvements may be expected in GPS loading results as mo problems are identified and solved in large reprocessing projects

original from paper original updated with new GPS data



f we can get GRACE and the inversions to agree...

we can use the global inversions to densify satellite gravimetry in

- space
  - proliferation of high density GPS networks
    - Europe heavily instruments
    - Plate Boundary Observatory
    - Japan
    - etc
  - GRACE optimistically 300 km; GPS in some regions down to 50 km
  - GPS spatial resolution gives us an opportunity to compare with in situ observations
- time
  - GRACE monthly (higher temporal solutions available at the expense o spatial resolution)

at low degrees

SLR are the only source of 30-year time series

a better understanding of the similarities and differences between and GRACE for the GRACE epoch would allow us to extend GRA periodic signals and trends forward and/or backward (?) in time

at high degrees we use GRACE to represent the truth

current comparisons are not as good as we would like to see; pos related to GPS technique errors

GPS data processing, background models, and analysis techniqu improving all the time

if we can get the GPS inversions to agree with GRACE, we could the inversions to extend GRACE back or forward in time

the same can be said of comparisons of GRACE with mass mode currently it would be difficult to rely on low degree information of the gravity field from GRACE only

until we understand the similarities and differences between GRACE SLR, and EOP better, we are (more or less) forced to rely on space geodetic techniques as substitution series

at higher degrees, there is still a need to improve the agreement betw global inversions of geodetic data and mass change models with GR estimates of the mass field

Chen et al., JGR (1999): geocenter from Lageos-1 and Lageos-2 tracking

compared to environmental mass estimates => fit well at the annual; little correlation at the monthly timescales

Cretaux et al., JGR (2002): compared multiple geocenter and model-predicted solutions; found that the seasonal amplitudes differed by up to a factor of 2 and t
phases differed by as much as 50 days

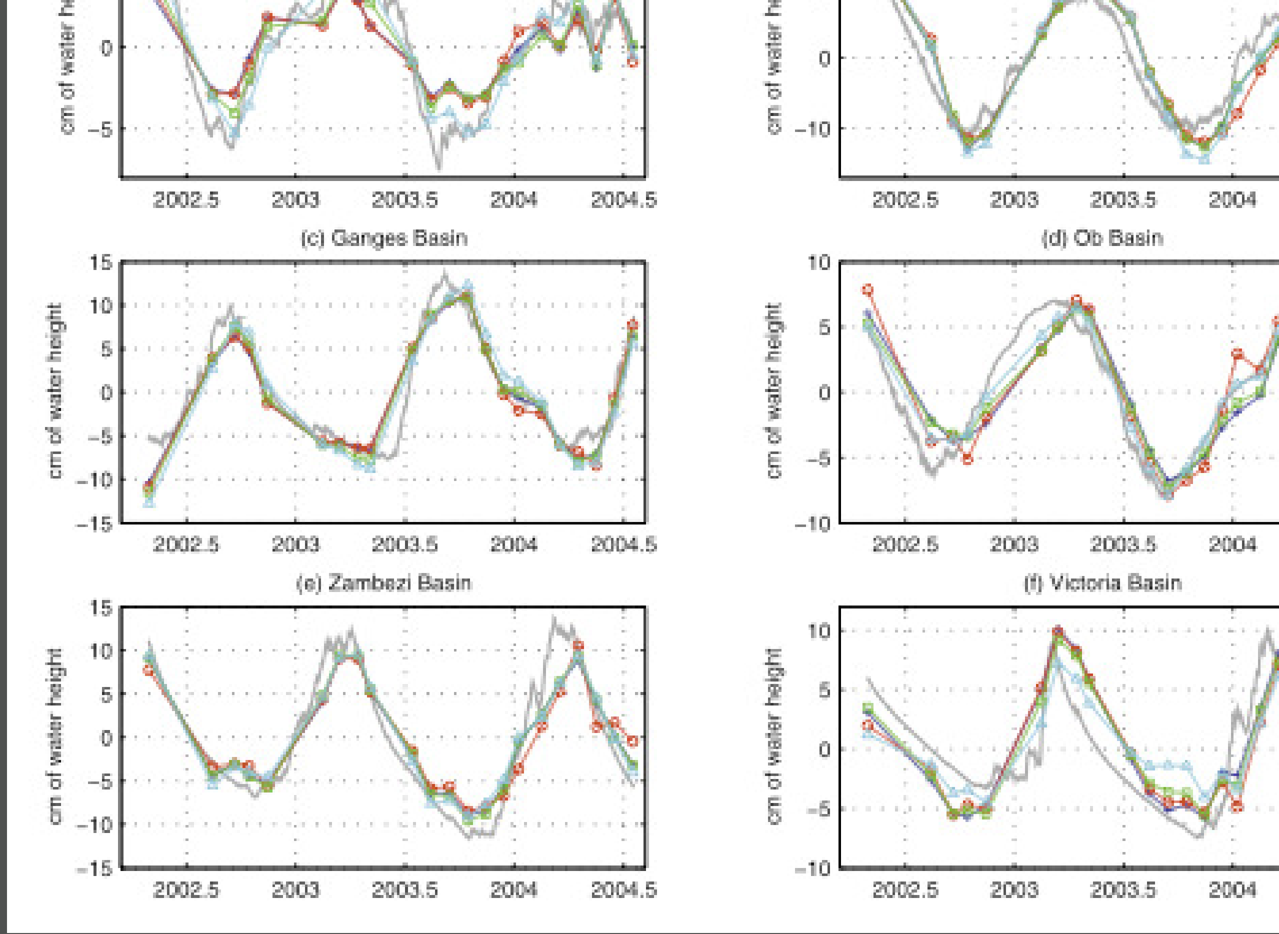
Blewitt and Clarke, JGR (2003): estimated geocenter from GPS; method suffers
sampling problems due to the lack of measurements in the oceans and remote la
ocations such as the tropics

Wu et al., JGR (2006): combined GPS, ocean bottom pressure, and GRACE dat
hybrid statistical optimal inversion technique to estimate spectral mass loading coefficients up to degree 50 including degree 1; estimated the uncertainty in thei
geocenter displacements to be less than 1 mm

Swenson et al., JGR (2008): GRACE and the OCGM ocean model output to est
degree 1 mass coefficients and geocenter motion, demonstrating that it is possib
determine the degree 1 Stokes coefficients without space geodetic data

so which degree-1 product do we use?

L (2005)



estimates of global terrestrial water storage changes by combining GRACE time variable gravity fields with degree-2 coefficients ΔC21, ΔS21, and ΔC20 from EO and/or SLR and degree 1 coefficients, ΔC11, ΔS11, and ΔC10, (geocenter varia rom SLR

compare with GLDAS

conclusions: substituting EOP and SLR estimates of ΔC21, ΔS21, and ΔC20 and SLR geocenter variations with GRACE data generally improves agreement with